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Preliminary Data from Lithium Hydride Ablation Tests Conducted by NASA-Ames Research Center

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ABSTRACT

A series of ablation tests of lithium hydride has been made by NASA-Ames in one of their high-enthalpy arc-heated wind tunnels. Two-inch diameter cylindrical samples of the hydride, supplied by A.I., were subjected to heating on their ends for time periods up to 10 seconds. After each test, the amount of material removed from each sample was measured. The rates of loss of material were correlated with the heat input rates in terms of a heat of ablation, which ranged from 2100 to 3500 Btu/lb. The higher values were obtained when the hydride contained a matrix such as steel honeycomb of steel wool.

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DATE May 5, 1970

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SECURITY CLASSIFICATION

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INTRODUCTION

The Magnetohydrodynamics and Gas Dynamics Research Laboratory of the NASA-Ames Research Center has, at the request of the AEC, conducted a series of ablation tests of lithium hydride in one of their high-enthalpy arc-heated test facilities. The test material was supplied by A.I.

On April 15, 1970 an informal meeting was held at NASA-Ames to discuss the results of these tests. Those present were:

Howard Stine (NASA)	Leonard Maki (A.I.)
William Carlson (NASA)	Roger Elliott (A.I.)
John Vorreiter (NASA)	John Sherwin (AEC-CPAO)
Charles Shepard (NASA)	

The discussion was most informative, and a summary of all the test results was given to us. In general, the tests showed that the lithium hydride ablated smoothly, without cracking or spalling. The effective heat of ablation was found to be within plus or minus 25% of the theoretical value, 2790 Btu/lb, which is found by taking the sum of the sensible heat required to raise the material to its melting point and the latent heat of fusion. The presence of an internal matrix, such as steel honeycomb or steel wool, tended to raise the heat of ablation (i.e. lower the rate of ablation).

DESCRIPTION OF TEST CONDITIONS

The tests were conducted in the Low-Density Constricted-Arc Supersonic Jet, which is described in Reference 1. This facility is capable of heating the driver gas to the extremely high enthalpy levels associated with entry from interplanetary trajectories, but is limited to gas stagnation pressures of about 0.03 atmospheres. Thus it can simulate the heating rates which occur during reentry to the atmosphere of the earth from satellite orbits, but not the aerodynamic pressures. Figure 1 illustrates the relationships between the tunnel settings and the reentry trajectory conditions. The line of constant heating rate marked on the figure shows that heating rates used in the tests were typical of those which will occur during the peak-heating period of the natural-decay trajectory. (Actually, the test values were somewhat higher than would occur in flight, because of the small diameter of the test specimens (2-in. diameter) as compared with the actual reactor shield diameter.)

Figure 1 also shows the operating capabilities of a higher-pressure facility at NASA-Ames, which was suggested for use if more tests are run. The operating conditions used in the RADE tests (Ref. 2) are also shown for comparison. These conditions were selected to simulate the heating associated with reentry of a body having a ballistic coefficient, W/C_DA, of 132 $lb.ft^2$, and would be inadequate for simulating the present trajectory.

The driver gas used in these tests was air, with an oxygen content of about 20 percent. One series of tests was made with the oxygen content set at 80 percent, but the test engineer expressed some doubts about the accuracy of the jet settings during these tests.

Aerodynamic heating rates in the test facility were measured by the use of calorimeters made in the shape and size of the test specimens. Measurements were made before and after each test. Impact pressures were also measured, and the enthalpy level was calculated from the pressure and heating rate values. (As a check, the enthalpy level is sometimes calculated by use of an energy balance, considering the gas flow, the electrical input, and the heat loss to the coolant.)

DESCRIPTIONS OF TEST SPECIMENS

The lithium hydride test material was supplied by A. I. in the form of 2-in. diameter cylinders, made by casting the material in 0.016 in. wall stainless steel (Type 321) tubes. NASA cut these cylinders into short (about 2-in.) lengths, and mounted them on stems for holding them in the jet. Some of the specimens had thermocouples installed in the interior of the material at various distances from the front faces, but the data from these thermocouplces had not been reduced at the time of our visit.

Some of the specimens were of solid lithium hydride, some were cast in a matrix of stainless steel wool, and some were cast in a matrix of stainless steel honeycomb. The honeycomb cells were about 1-in. diameter, with the steel being 0.001 in. thick. In some cases, the cells were placed axially with respect to the cylinder, and in others the cells were placed crosswise.

The steel shells were left around the hydride for some of the tests and were removed for other tests. It was found that the hydride ablated more rapidly than the steel, leaving a raised lip of about 3/8 in. height around the specimen. A calorimeter was made with such a lip, and it was found that the heating rate at the center of the specimen was reduced about 10 percent as compared with a flat-faced specimen.

The duration of each test was between 4 and 11 seconds. It was found that the shape of the face of the test specimen changed during a test. Those specimens having a steel shell tended to melt back nearly uniformly, leaving the shell standing. The specimens without a shell tended to become curved, with a radius of curvature of about 1.6 to 2.5 times the radius of the basic cylinder. Some tests were made by starting with specimens that had already been ablated, thus starting with a naturally-formed shape instead of a flat face. The heating rates reported in the data summary were corrected for the effects of specimen shape.

RESULTS OF TESTS

The test results have been correlated in terms of a parameter Q*, called "effective heat of ablation". Q* is defined as the ratio of the net heat input at the heated surface to the rate of mass loss from that surface. If the conduction losses into the material and the radiation losses from the surface are small, Q* may be found approximately by dividing the aerodynamic heating rate by the rate of mass loss. For a material that ablates by a simple process of melting, Q* is theoretically equal to the sum of the sensible heat required to bring the material up to its melting temperature and its latent heat of fusion. According to NASA, the theoretical value of Q* for lithium hydride is 2790 Btu/lb, and the test results were normalized by dividing them by this value.

Table I, below, summarizes the results of the tests. The detailed results are ~~given in~~ Table II, attached to the end of this report.

TABLE I

EFFECTIVE HEAT OF ABLATION OF LITHIUM HYDRIDE

(Relative to Theoretical Value of 2790 Btu/lb)

Matrix in Material	Initial Shape	Q*/2790 With Shell	Q*/2790 No Shell
None	Flat	0.875	0.751
"	Rounded	---	1.029
Steel Wool	Flat	1.075	0.854
" "	Rounded	---	1.204
Honeycomb (Crosswise)	Flat	1.243	0.367
Honeycomb (Axial)	Flat	1.145	0.870
Honeycomb (Axial) (80% O_2)	Flat	0.887(?)	---

Several different methods of reducing the data were tried, based on the rate of mass loss at the centerline of each model and on the average rate of mass loss over the surface. The initial heating rates and the final heating rates were tried, and it was found that the use of the average of the initial and final heating rates gave the best correlation.

The results indicate that the presence of a matrix such as steel wool or honeycomb tends to increase the effective heat of ablation, as compared with the values for solid lithium hydride. This effect may be partially due to the heat absorbed in melting ~~the steel and~~ the heat radiated from the steel surfaces. It may also be due to the restriction to running-off of the molten hydride, causing it to become superheated as it left the surface. The effect of the steel shell surrounding the test specimen is similar to the effect of an internal matrix, and probably acts in about the same way.

The two tests run with 80 percent oxygen in the jet showed a significant drop in the effective heat of ablation as compared with the values from the tests in air. The test engineer, however, said that he has doubts about the calibration of the jet for these tests, and that the results should be disregarded until they can be verified.

RECOMMENDATIONS AND DISCUSSION

The following recommendations were made with regard to future tests:

1. Some tests should be run in an arc-jet having a higher impact pressure, if possible.

2. More tests should be run with increased oxygen content in the driver gas.

3. A test sample should be made with lithium hydride case in a closed shell, so that possible swelling and bursting of the shell could be studied.

4. Some samples of tantalum-10-tungsten should be tested to see what would happen if all of the hydride were to be removed.

The meeting ended with a general discussion of possible design modifications that might enhance the ability of the reentry body to resist damage. Some of the points discussed were:

1. The transition section between the aft shield and the radiator might be covered with a heat-shield, and the connection to the radiator be designed to break away at a low heat rate. This would stabilize the body in a nose-first attitude, and also would reduce its ballistic coefficient. Additional lithium hydride or some other protective material could then be added to the nose of the body, leaving the sides of the shield as they are.

2. We might consider the use of a honeycomb matrix having a smaller cell size and thicker walls, provided that the performance of the radiation shield is not reduced excessively.

3. There might be some substances which could be added to the lithium hydride to increase its viscosity in the liquid state, thereby reducing the rate of run-back and increasing its effective heat of ablation.

4. We might consider putting a layer of a good heat-shield material such as boron nitride around the Ta-10W shield, as an additional protection in case all of the hydride was lost.

REFERENCES

1. Charles E. Shepard, et al., "A High Enthalpy Plasma Generator for Entry Heating Simulation", NASA Technical Note D-4583, May 1968.
2. J. E. Arnold and L. D. Montgomery, "Test Report of the SNAP Reactor Ablation-Disintegration Experiment (RADE) in a Hyperthermal Wind Tunnel", NAA-SR-TDR No. 12136, Oct. 31, 1966.

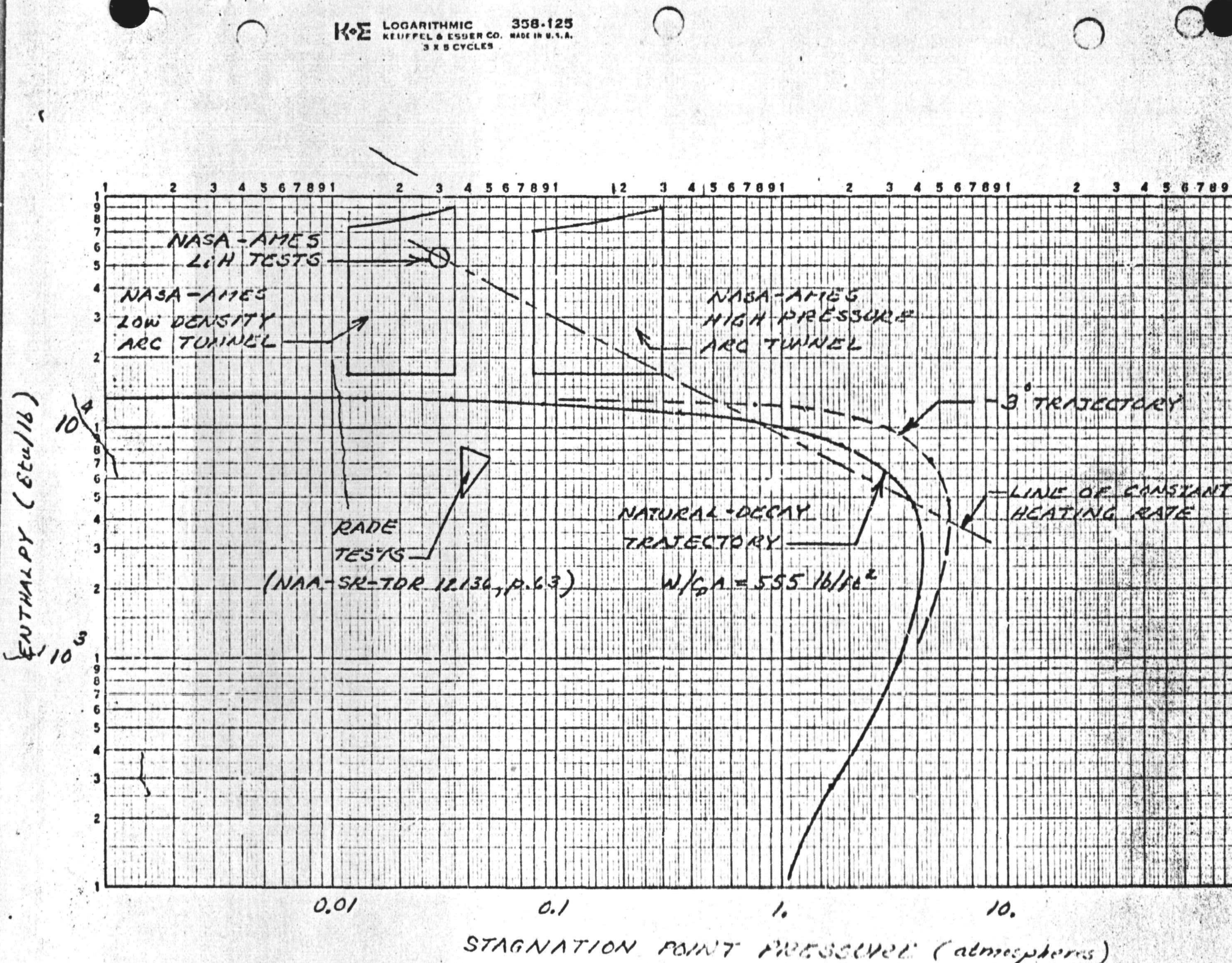

Figure 1: Arc-Jet Tunnel Capabilities and Trajectory Simulation Requirements for Lithium Hydride Tests

TABLE II: NASA-AMES TEST DATA FOR LITHIUM HYDRIDE ABLATION

MATRIX MATERIAL	OUTER SHELL ?	INITIAL SHAPE	DATE OF RUN	RUN DURATION (SEC)	MASS LOSS RATE, $\dot{m}$ (LB/FT²-SEC) TOTAL	MASS LOSS RATE, $\dot{m}$ CENTER-LINE	HEATING RATE, $\dot{q}$ (BTU/FT²-SEC) INITIAL	HEATING RATE FINAL	10	EFFECTIVE HEAT OF ABLATION Q^* (BTU/LB) INITIAL, TOTAL	INITIAL, C.LINE	FINAL, C.LINE	AVG, C.LINE	REPORTED VALUES
NONE	YES	FLAT	1-14-70	10.81	0.183	–	736	675		4021	–	–	–	
			1-19-70	4.87	0.181	0.280	734	675		4057	2621	2411	2516	
			1-21-70	4.72	0.167	0.297	734	675		4375	2471	2273	2372	2416
NONE	NO	FLAT	1-21-70	4.42	0.338	0.401	735	1131		2174	1833	2820	2326	
			2-19-70	5.41	0.392	0.349	651	684		1661	1865	1959	1912	2119
NONE	NO	ROUNDED	2-20-70	5.38	0.378	0.302	855	879		2262	2831	2911	2871	2871
ST. WOOL	YES	FLAT	1-23-70	4.70	0.123	0.235	735	675		5961	3128	2872	3000	3000
ST. WOOL	NO	FLAT	1-23-70	4.38	0.411	0.375	735	1102		1788	1760	2937	2450	
			2-19-70	5.17	0.319	0.312	651	812		2091	2087	2603	2345	2382
			1-27-70	5.80	0.275	0.337	578	986		2175	1779	2926	2350	
ST. WOOL	NO	ROUNDED	2-20-70	5.07	0.389	0.309	916	1170		2355	2964	3754	3359	3359
HONEYCOMB CROSSWISE	YES	FLAT	3-20-70	5.45	0.136	0.167	668	543		4926	4000	3251	3626	
			3-20-70	5.61	0.119	0.183	668	543		5623	3650	2967	3309	3468
HONEYCOMB CROSSWISE	NO	FLAT	3-12-70	5.36	0.307	0.314	774	989		2521	2464	3150	2808	
			3-13-70	5.30	0.389	0.379	615	902		1602	1649	2412	2028	2418
HONEYCOMB AXIAL	YES	FLAT	3-20-70	6.12	0.115	0.169	655	532		5681	3887	8157	3522	
			3-20-70	7.06	0.126	0.207	655	532		5181	3164	2570	2867	3195
HONEYCOMB AXIAL	NO	FLAT	3-12-70	5.57	0.339	0.355	774	989		2283	2180	2786	2483	
			3-16-70	5.57	0.307	0.325	615	925		1990	1893	2848	2371	2427
HONEYCOMB AXIAL	YES	FLAT	3-31-70	7.23	0.138	0.186	514*	418*	80% O_2	3720	2762	2247	2505	
			3-31-70	6.99	0.127	0.167	514*	418*	80% O_2	4046	3077	1810	2444	2475

* VALUES UNCERTAIN

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